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EFFICIENT USE OF MODULARIZATION IN TRANSPORTATION  
SYSTEMS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This study suggests a means of most economically utilizing several different modes of transportation (container sizes). Using the digital computer, a computer program has been written which will define the optimum module dimensions on the basis of least total internal cubic loss for a variable set of container sizes. In order to yield the most economically efficient dimensions, the relative frequency of use of each container size was also incorporated into the minimum cubic loss criterion.		

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## PREFACE

This work was performed under Project 1J662713D552 Packaging Exploratory Development, Task - 02, Work Unit - 023, Dimensional and Density Parameters for Modular Containers for Convenience Foods primarily in response to a DA approved QMDO for a Food Service System for the soldier in the field. To quote, "Food will be packaged to serve a prescribed number of persons. The module size, that quantity of food required to serve a prescribed number of persons, must be scientifically determined to afford the greatest practicability and reduce to a minimum waste or overissues."

The objective of this study is to define the means for the most effective use of cargo space (optimum-module) within varying modes of transportation. Beyond this immediate application, the computer program for evaluating degree of efficiency of space utilization can be applied to other storage, transportation or stowage problems.

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## EFFICIENT USE OF MODULARIZATION IN TRANSPORTATION SYSTEMS

### INTRODUCTION

Efficient use of transportation media in terms of space utilization has long been a problem not only for the military but private industry as well. The common method of handling goods is to store these goods in rectangular units (modules) which are mounted on pallet bases easily handled by forklifts. These modules in turn are placed in various container sizes (trucks, rail cars, etc.) and shipped to their destination. Since transportation costs are directly related to container size, any wasted space manifests itself as an economic loss and clearly, there is cubic loss incurred in placing modules within containers.

The Army, in its search for ways to improve Food Service for the Army in the Field, has recognized that to achieve overall transportation efficiency a standard module size is desirable in which to move subsistence items from the manufacturing or central CONUS assembly point through the distribution system to or very near the point of ultimate use. Clearly, there will be wasted space if one sized module is to be transported within several differently sized containers. The total wasted space, however, can be minimized by a proper choice of module size for the given set of containers. This report deals with a description of a computer program written to determine the optimum module dimensions for a variable number of container sizes. It is recognized that several valid and significant constraints exist, such as the DoD grid system, pallet support sets and storage racks, and pallet retrieval systems, that would govern the adoption of new or unusual module sizes as might result from use of the program. However, the computer program is flexible enough to encompass such constraints. Beyond determining optimum sizes per se, the program will permit evaluation of the efficiencies of existing or proposed systems.

## OPTIMUM MODULE DIMENSIONS

In deciding upon one module size to fit into several container sizes the initial problem is to define what is meant by "best size". The criterion chosen in this study is to minimize the total wasted space incurred in shipping the one module size within the given container sizes. Consider Figure 1 showing the module within one container. Clearly, the volume loss is the sum of the top volume loss plus the volume loss incurred in the use of pallets (necessary if forklifts are to be used in moving the modules). The total volume loss for the given set of containers is equal to the sum of the volume losses in each container.

If, however, one container size is used more frequently than another, the volume losses for each container should have a weighting factor which reflects that relative loss.

Since the relationship between total volume loss for a set of containers and module size is not easily defined, an alternative approach utilizing the computational capability of a digital computer is suggested. Establishing some minimum module height, compute the total volume loss for the set of containers. Storing that information, change the module height by some small increment and compute the total volume loss again. Comparing these two total volume losses with each other, keep that module height corresponding to the smaller of the two total volume losses. Changing the module height again by the same increment, run through the same comparative scheme again and again until a maximum module height is reached. The information which should be kept throughout this iterative procedure is the module height corresponding to the least total volume loss plus any other values of the module height corresponding to that same total volume loss. Refer to Figure 2 which is a flow chart of the computer program used to perform the iterative process. Although Figure 2 is not a strict computer algorithm, the flow of logic is well represented. In computing the optimum module length and width, the same procedure is used, except that now there is no loss due to pallet height.

In the example used in the program (Efficient Module, Appendix B), the dimensional data (Table 1) was taken from the Military Traffic Management and Terminal Service Western Area Container Conference given during the month of March 1971. The eleven sea container sizes used represent the primary mode of shipment from the West Coast. The weighting factors were derived from the tonnage distribution during the first half of FY 71. Since total tonnage is a function of container size as well as frequency of use, the tonnage information was modified (by using the relative container sizes) to yield the appropriate weighting factors. This computer program incorporates such weighting factors (see Frequency Factor Conversion, Appendix A). The minimum module height, width, and length was chosen as 30 in. (0.76 m), maximum dimensions as 70 in. (1.78 m), pallet height as 5.4375 in. (0.138 m) and module increment as 0.25 in. (0.635 cm).

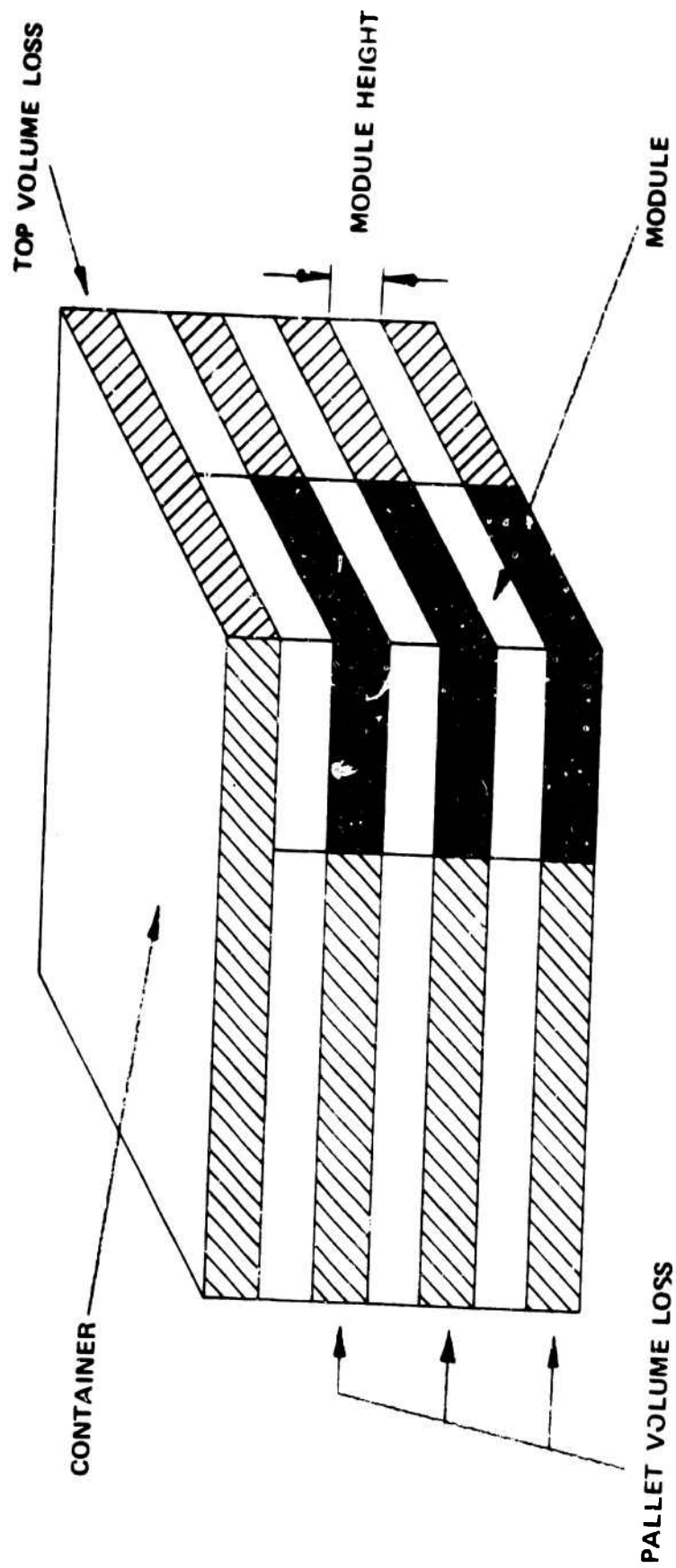
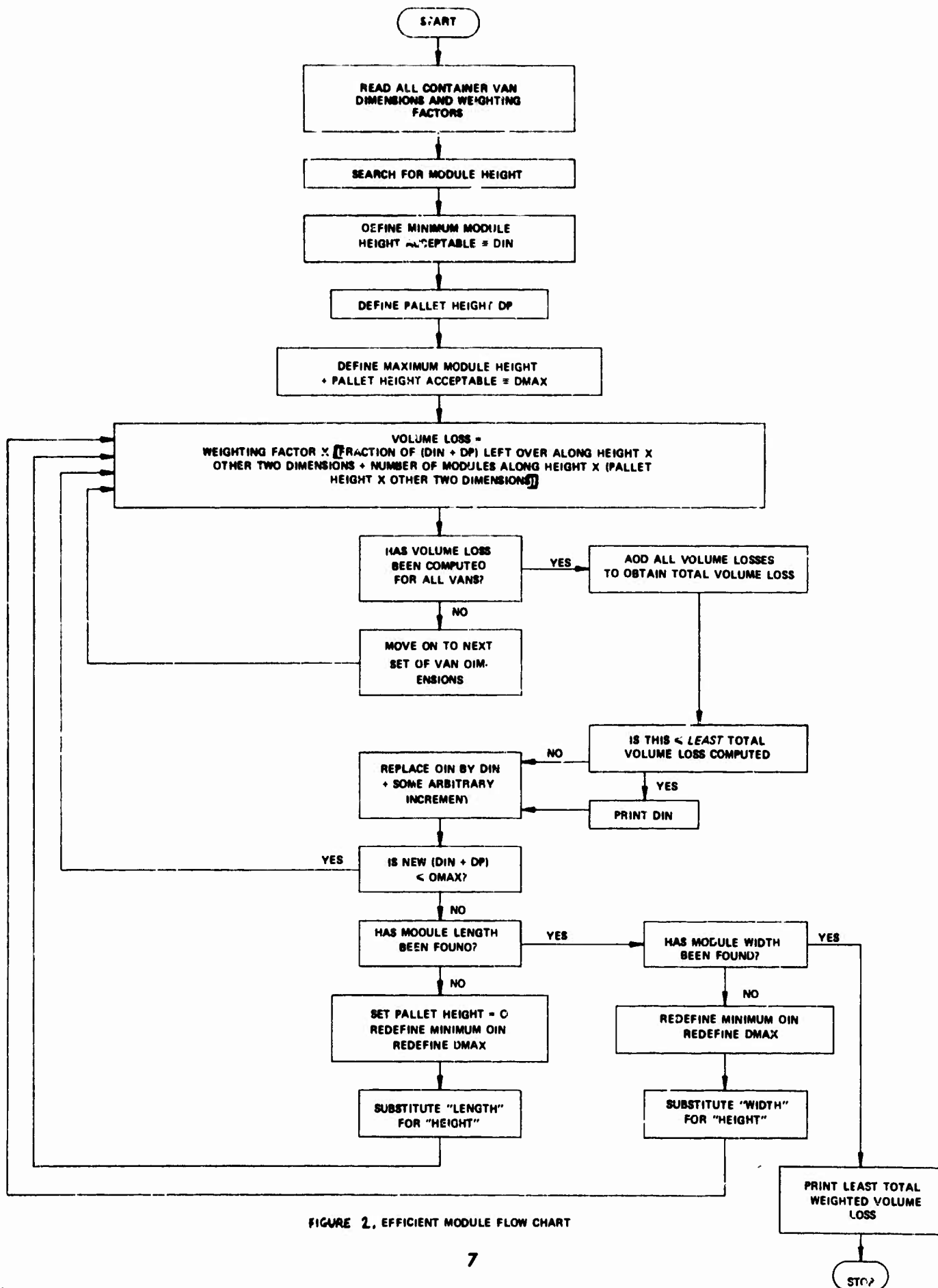


FIGURE 1. INTERNAL CUBIC LOSS



**TABLE 1**  
**CONTAINER DIMENSIONAL DATA**

		Height	Width	Length	Maximum Cargo Weight lb (kg)	Tonnage Per Year (%)
1)	SEALAND	7'10" 94"(2.39m)	7'8" 92"(2.34m)	34'7" 415"(10.54m)	45,000 (20411 kg)	65
2)	MATSON	7'10.5" 94.5"(2.40m)	7'8.5" 92.5"(2.35m)	23'6.5" 282.5"(7.18m)	46,200 (20956 kg)	6
3)	APL	7'4" 88"(2.24m)	7'9" 93"(2.36m)	19'6" 234"(5.94m)	40,300 (18280 kg)	6
4)	PFEL	7'4" 88"(2.24m)	7'8" 92"(2.34m)	19'5" 233"(5.82m)	40,300 (18280 kg)	5
5)	STATES	7'6" 90"(2.29m)	7'10" 94"(2.39m)	19'7" 235"(5.97m)	38,000 (17236 kg)	4
6)	AML	8'4.125" 100.125"(2.54m)	7'9.5" 93.5"(2.37m)	39'5.75" 473.75"(12.03m)	46,000 (20865 kg)	2
7)	AML	7'4" 88"(2.24m)	7'10" 94"(2.39m)	19'7" 235"(5.97m)	40,000 (18144 kg)	2
8)	MILVANS	7'1" 85"(2.16m)	7'6" 90"(2.29m)	19'4" 232"(5.89m)	40,000 (18144 kg)	2
9)	SEATRAN	8'8" 104"(2.64m)	7'8" 92"(2.34m)	26'5" 317"(8.05m)	46,000 (20865 kg)	4
10)	U.S. LINES	7'10" 94"(2.39m)	7'9" 93"(2.36m)	39'6" 474"(12.04m)	46,000 (20865 kg)	1.5
11)	U.S. LINES	7'6" 90"(2.29m)	7'10" 94"(2.39m)	19'7" 235"(5.97m)	40,650 (18435 kg)	1.5

To utilize the program which is based on the weighted total internal cubic loss minimization criterion listed in Appendix B, one need only supply the interior dimensions ( $D(I,J)$ ), weighting factors ( $FAC(I)$ ), module increment ( $DELD$ ), pallet height ( $DP$ ), and the starting and ending module dimensions at the appropriate points in the program. In assigning the container dimensions  $D(I,J)$ , an allowance should be made where necessary for module maneuverability to facilitate loading and unloading. Thus, the program is completely general and can be applied to any number of containers at the will of the programmer. In the example problem, running time (including peripheral functions) is less than seven minutes. Certainly no one would perform the same calculations by hand.

The results of the example used in the program Efficient Module yield height 38.5 in. (0.98 m), width and length 46.0 in. (1.17 m). An interesting exercise was to compare the percentage of available space from the eleven containers considered that could be filled using the standard module (43 in. (1.09 m) and 52 in. (1.32 m) maximum length and width, no fixed height) with that filled by the Efficient Module. For this purpose the standard module height was set equal to the Efficient Module height (38.5 in. or 0.98 m) and the container space available was the sum of the container volumes with each container's volume being weighted by the approximate number of relative trips per year for that container. The result was that the standard module was capable of filling approximately 63% of the space and the Efficient Module filled approximately 80%.

There could be instances with heavy materials where completely filled modules would result in the overloading of containers. Therefore, a smaller program was also written to compute the maximum cargo weight per module in each of the containers. Clearly, if the container and module sizes are known along with the pallet height, weight, and maximum container cargo weight, the maximum cargo weight per module can be easily determined. This program prints out the results in an order corresponding to the order in which the container dimensions were read into the program.

### CONCLUDING COMMENTS

Herein has been suggested a criterion and an easy means of selecting the best one module size to be used in a multitude of container sizes. If the criterion is accepted, the computer program is very easily utilized by anyone with programming experience. The generality of the program also lends itself to analyzing the effect of module base (pallet) overhang changes on the volume lost in a set of containers.

## REFERENCES

Carrabino, Joseph D.; *An Engineering Analysis of Cargo Handling*; Los Angeles, California; The University of California Press; July 1957.

Military Traffic Management and Terminal Service; *Container Conference Agenda*; San Francisco, California; March 1971.

Hendee, John R.; *Tools of the Trade*; Package Development, Scarborough Publishing Co., Ltd.; Briarcliff Manor, N. Y.; January/February, 1972; pages 13-14.

**APPENDIX A**

**FREQUENCY FACTOR CONVERSION**

## Appendix A

### Frequency Factor Conversion

To convert from tonnage distribution to frequency factors, select the smallest volume (Milvan) as a base and normalize the tonnage information as follows:

$$\frac{(\# \text{Trips/yr})_1}{(\# \text{Trips/yr})_2} = \frac{(\text{Volume})_2}{(\text{Volume})_1} \times \frac{(\text{Tonnage/yr})_1}{(\text{Tonnage/yr})_2}$$

Define:

$$\begin{aligned} i\text{th Frequency Factor} &\equiv \frac{(\text{Tonnage/yr})_{\text{Milvan}}}{(\# \text{Trips/yr})_{\text{Milvan}}} \times (\# \text{Trips/yr})_i \\ &\equiv \text{FAC}(i) \end{aligned}$$

or

$$\text{FAC}(i) = \frac{(\text{Volume})_{\text{Milvan}}}{(\text{Volume})_i} \times (\text{Tonnage/yr})_i$$

The frequency factors corresponding to the eleven container sizes used in the example are shown in table A-1.

TABLE A-1  
FREQUENCY FACTORS

1)	32.0
2)	4.0
3)	6.0
4)	5.0
5)	4.0
6)	1.0
7)	2.0
8)	2.0
9)	2.0
10)	0.6
11)	1.3

**APPENDIX B**

**EFFICIENT MODULE PROGRAM WITH MAXIMUM MODULE WEIGHT**

```

      1JOB      NOCARDS, NOLIST
      2ZE
      3FORTRAN
      4
      5      EFFICIENT MODULE      BOZIUU. 111
      6      THIS PROGRAM DETERMINES THE BEST MODULE SIZE FOR A SET OF
      7      CONTAINERS ON THE BASIS OF LEAST TOTAL INTERNAL CUBIC LOSS
      8      AND FREQUENCY OF CONTAINER USE
      9      DIMENSION D(11,3), FAC(11)
      10     THE FOLLOWING IS THE WEIGHTED INTERNAL CUBIC LOSS
      11      $F(D1,D2,D3,DP,OIN,WF) = WF * (D1 - AINT(D1/(OIN * DP))) * D1 * D2 * D3$ 
      12     READ IN THE CONTAINER USEABLE DIMENSIONS
      13     READ 10, ((O(I,J), J = 1,3), I = 1,11)
      14     FORMAT (8F7,3)
      15     READ IN THE FREQUENCY PARAMETERS, MODULE INCREMENT, AND PALLET HEIGHT
      16     READ 40, (FAC(I), I = 1,11), DELD, DP
      17     FORMAT (11F5,1/(2F10,2))
      18     PRINT 50
      19     FORMAT (24X,13HMODULE HEIGHT)
      20     K = 0
      21     FA = 0.0
      22     SET THE INITIAL MODULE HEIGHT
      23     DIN = 30.0
      24     SET THE MAXIMUM MODULE HEIGHT PLUS PALLET HEIGHT ALLOWABLE
      25     OMAX = 70.0 + 5.4375
      26     GO TO 1
      27     K = K + 1
      28     L = 0
      29     CONTINUE
      30     THIS LOOP COMPUTES THE TOTAL WEIGHTED INTERNAL CUBIC LOSS
      31     F1 = 0.0
      32     DO 21 I = 1,11
      33     O1 = D(I,1)
      34     D2 = D(I,2)
      35     D3 = D(I,3)
      36     WF = FAC(I)
      37     F1 = F1 + D1 * O2 * O3 * OP * OIN * WF1 + F1
      38     IF (L,GE,1) GO TO 3
      39     FA = F1
      40     L = L + 1
      41     CONTINUE
      42     IF (F1,GT,FA) GO TO 7
      43     IF (F1,LT,FA) GO TO 5
      44     PRINT 6, DIN
      45     FORMAT (//20X,16H DUPLICATE DIN = , F6,2)
      46     GO TO 7
      47     FA = F1
      48     PRINT 8, DIN
      49     FORMAT (//20X,16H MODIFIED OIN = , F6,2)
      50     DIN = DIN + DELD
      51     OPL = DIN + DP
      52     IF (OPL,LE,OMAX) GO TO 30
      53     THE LEAST TOTAL VOLUME LOSS IS FA
      54     PRINT 12, FA
      55     FORMAT (//20X,15H FA = , E16,9)

```

```

C   THE LAST MODIFIED DIN AND ANY SUCCEEDING DUPLICATE DINS YIELD FA
    PRINT 51
51  FORMAT(//11X,40HTHE LAST MODIFIED DIN AND ANY SUCCEEDING,//19X,
      1 23H DUPLICATE DINS YIELD FA)
      IF(K.EQ.2) GO TO 25
      DP = 0.0
      IF(K.EQ.1) GO TO 22
      PRINT 4
4    FORMAT(//24X,12HMODULE WIDTH)
C    SET THE INITIAL MODULE WIDTH
      DIN = 30.0
C    SET THE MAXIMUM MODULE WIDTH ALLOWABLE
      DMAX = 70.0
      DO 13 I = 1,11
        DS = D(I,1)
        D(I,1) = D(I,2)
13     D(I,2) = DS
        GO TO 9
22    PRINT 14
14    FORMAT(//24X,13HMODULE LENGTH)
C    SET THE INITIAL MODULE LENGTH
      DIN = 30.0
C    SET THE MAXIMUM MODULE LENGTH ALLOWABLE
      DMAX = 70.0
      DO 15 I = 1,11
        DS = D(I,1)
        D(I,1) = D(I,3)
15     D(I,3) = DS
        GO TO 9
25    STOP
      END

```

```

$LOAD
94.000 92.000 415.000 94.500 92.500 282.500 88.000 93.000
234.000 88.000 92.000 213.000 90.000 94.000 235.000 100.125
93.500 473.750 88.000 94.000 235.000 85.000 90.000 232.000
104.000 92.000 317.000 94.000 93.000 474.000 90.000 94.000
235.000
32.0 4.0 6.0 5.0 4.0 1.0 2.0 2.0 2.0 0.6 1.3
0.25 5.4375
$EOJ

```

# MODULE HEIGHT

DUPLICATE DIN = 30.00  
MODIFIED DIN = 30.25  
MODIFIED DIN = 30.50  
MODIFIED DIN = 30.75  
MODIFIED DIN = 31.00  
MODIFIED DIN = 31.25  
MODIFIED DIN = 31.50  
MODIFIED DIN = 31.75  
MODIFIED DIN = 32.00  
MODIFIED DIN = 32.25  
MODIFIED DIN = 32.50  
MODIFIED DIN = 32.75  
MODIFIED DIN = 33.00  
MODIFIED DIN = 33.25  
MODIFIED DIN = 33.50  
MODIFIED DIN = 33.75  
MODIFIED DIN = 34.00  
MODIFIED DIN = 34.25  
MODIFIED DIN = 34.50  
MODIFIED DIN = 34.75

MODIFIED DIN = 35.00  
MODIFIED DIN = 35.25  
MODIFIED DIN = 35.50  
MODIFIED DIN = 35.75  
MODIFIED DIN = 36.00  
MODIFIED DIN = 36.25  
MODIFIED DIN = 36.50  
MODIFIED DIN = 36.75  
MODIFIED DIN = 37.00  
MODIFIED DIN = 37.50  
MODIFIED DIN = 37.75  
MODIFIED DIN = 38.00  
MODIFIED DIN = 38.25  
MODIFIED DIN = 38.50  
FA = 0.322130292E+08

THE LAST MODIFIED DIN AND ANY SUCCEEDING  
DUPLICATE DINS YIELD FA

MODULE WIDTH

DUPLICATE DIN = 30.00  
MODIFIED DIN = 30.25  
MODIFIED DIN = 30.50  
MODIFIED DIN = 46.00

FA = 0.231709943E+07

THE LAST MODIFIED DIN AND ANY SUCCEEDING  
DUPLICATE DINS YIELD FA

MODULE LENGTH

DUPLICATE DIN = 30.00

MODIFIED DIN = 30.25

MODIFIED DIN = 30.50

MODIFIED DIN = 30.75

MODIFIED DIN = 31.00

MODIFIED DIN = 31.25

MODIFIED DIN = 31.50

MODIFIED DIN = 31.75

MODIFIED DIN = 37.50

MODIFIED DIN = 45.75

MODIFIED DIN = 46.00

FA = 0.214610650E+07

THE LAST MODIFIED DIN AND ANY SUCCEEDING  
DUPLICATE DINS YIELD FA

FORTRAN IV, CD225H6,004, MAY 1971  
\$JOB NOCARDS, VOLIST

\$ZE

\$FORTRAN

```
C      MAXIMUM MODULE WEIGHT
C      THIS PROGRAM DETERMINES THE MAXIMUM CARGO WEIGHT PER MODULE FOR
C      EACH CONTAINER SIZE
      DIMENSION WPM(11), NPC(11), D(11,3), WC(11)
      REAL NPC
C      THE FOLLOWING COMPUTES THE NUMBER OF MODULES STORABLE
C      IN ONE CONTAINER
      NP(D1, D2, D3, DM, DMW, DML) = AINT(D1/DM)*AINT(D2/DMW)*
1AINT(D3/DML)
C      READ IN THE CONTAINER DIMENSIONS
      READ 10, [(D(I,J),J=1,3),I=1,11]
10      FORMAT(8F7,3)
C      READ IN THE MAXIMUM CARGO WEIGHT FOR EACH CONTAINER
      READ 12, [WC(I),I=1,11]
12      FORMAT(6F10,1)
C      READ IN THE PALLET WEIGHT, MODULE HEIGHT, WIDTH AND LENGTH,
C      AND PALLET HEIGHT
      READ 11, WP, DMH, DMW, DML, DP
11      FORMAT(5F10,4)
      DM = DMH + DP
C      THE FOLLOWING LOOP ACCOMPLISHES THE PROGRAM OBJECTIVE
      DO 5 I=1,11
      D1 = D(I,1)
      D2 = D(I,2)
      D3 = D(I,3)
      NPC(I) = NP(D1, D2, D3, DM, DMW, DML)
5      WPM(I)=(WC(I)-NPC(I)*WP)/NPC(I)
      PRINT 6
6      FORMAT(/20X,31HMAXIMUM CARGO WEIGHT PER MODULE,
1/26X,18HIN ASCENDING ORDER)
      PRINT 4, [WPM(I),I=1,11]
4      FORMAT(/27X, E16,9)
      STOP
      END
```

MAXIMUM CARGO WEIGHT PER MODULE  
IN ASCENDING ORDER

0.118500000E+04

0.186000000E+04

0.195000000E+04

0.195000000E+04

0.183500000E+04

0.108500000E+04

0.193500000E+04

0.793500001E+04

0.185166667E+04

0.108500000E+04

0.196750000E+04